Prototype of multi-filament electron curtain accelerator

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Abstract In this paper, we present a prototype of electron curtain accelerator with 200 kV high voltage and an average beam current around 20 mA with beam width about 600 mm. Several physical and mechanical design of this facility is discussed in detail thoroughly, in conjunction with 3D software modeling and simulation. And some efforts to modulate cathode structure have been done to improve the electron beam uniformity effectively.

Key words Vertical electron curtain accelerator, Cathode structure, High voltage

1 Introduction

Electron curtain Accelerators play an important role in many different industries, such as printing, curing, coating and packing to promote product quality meanwhile to reduce Volatile Organic Compounds to protect global environment[1–3]. Based on catholic experience accumulated in our previous products of Nuctech Co Ltd, our division sets out to develop an electron curtain accelerator which can generate 200 kV electron beam and about 20 mA beam current with 600mm beam width cooperating with Beijing Institute of Graphic Communication at beginning of 2012. The main purpose of this paper is to provide the reader with the design considerations in the R & D process and offer the up-to-date advancement of our prototype.

2 Physical design

Electron curtain accelerators belong to low-energy electron accelerators, which are mainly composed of high voltage power supply, vacuum system, electron source and accelerating system, shielding system, nitrogen inerting system and process control system, as shown in Fig.1.

2.1 High voltage design

We have developed a DC high voltage power supply cooperated with a company leading in X-ray machine manufacture according to our requests as shown in Fig.2, which can generate a DC high voltage up to 200 kV and 20 mA current at most with less than 10% voltage ripple.

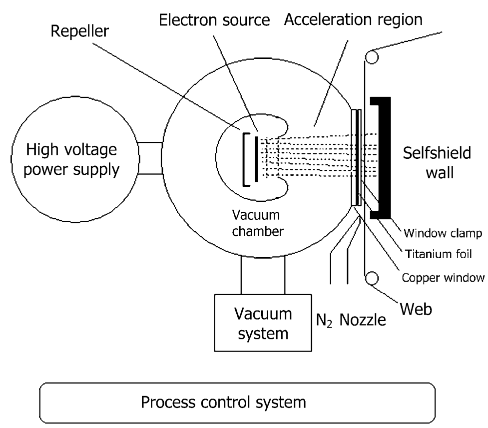

Fig.1 Electron curtain accelerator diagram.

High voltage cable from transformer passes the oil chamber to reach cylinder conductors, which are connected with filaments, on a round glass plate to separate vacuum chamber from the oil one. The output high voltage cable inserted to high voltage feed on oil chamber has three conductors: one of them is high voltage base, another one for filament and the last one for grid bias voltage. A cone shape high voltage

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connector with conductors at top surrounded by insulating epoxy has been adopted to decrease possible electrical breakdown. No matter where high voltage cable is, in vacuum or in oil, it was shielded by tubular conductors made of stainless steel as grading ring, as shown in Fig.2.

Fig.2 200 kV/20 mA high voltage power supply.

A ceramic plate is used to seal oil chamber meanwhile to isolate high voltage from chamber wall with ground potential. Designers also make use of four other ceramic columns to support filament housing at high voltage in vacuum chamber. Besides two inspection windows were set at best spots to observe possible high voltage breakdown phenomenon in vacuum or oil chamber in Fig.3.

2.2 Vacuum design

There were three main problems to be solved in vacuum design: vacuum sealing, vacuum sparking and vacuum material selection. The first concern associates with national standard of vacuum design, which could be found completely in most vacuum handbook. The second one is related critical static electric field surrounding high voltage conductors and conductor surface roughness in vacuum and oil chamber, which could be solved by electro-magnetic software simulation and manufacturing craft. Last but not least, material selection in vacuum is not a negligible issue, since outgas rate, electrical breakdown and high voltage insulation all have intimate relationship with material selection in vacuum.

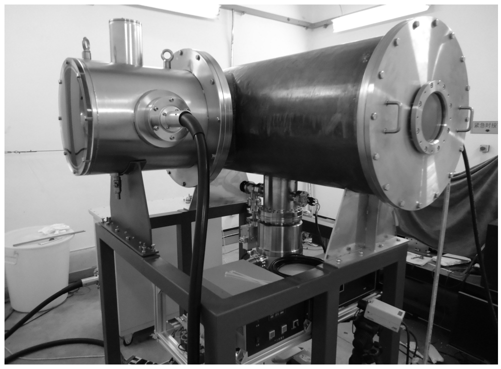

Fig.3 Electron curtain accelerator.

The main body of L shape vacuum and oil chamber is made of stainless steel, and a lead shell covers the vacuum chamber (Fig 3). A vertical window membrane is on the opposite of oil chamber to avoid electrical field distortion if close to vacuum pump pipeline junction at the bottom of vacuum chamber. To facilitate installation and replacement of components, there are four openings on the chambers in total, three on vacuum chamber and one on oil chamber. O shape Viton rings with lower outgas were used to seal vacuum. Materials that used in vacuum chamber are tungsten alloy for filament, copper for filament conductor, stainless steel for filament housing and supports, glass disk and ceramic cylinder for insulation, and molybdenum for grid poles.

2.3 Filament design

Multi-filament cathodes & grid structures within filament housing were designed carefully to generate uniform beam distribution outside of window membrane[4]. Compared to single longitudinal cathode, multi-filament cathodes are more competitive in width expansion and beam uniformity. In order to decrease distribution modification by effect of heated filament expansion, a scheme of filaments vertical fixation was adopted as shown in Fig.4, which means electron beam was accelerated by high voltage horizontally.

When electrons emit from filaments, they pass extracting grid firstly which control beam current. Then the electrons pass through the secondary grid which can not only uniform their distribution at foil window but also shield filament from high voltage spark in high acceleration region.

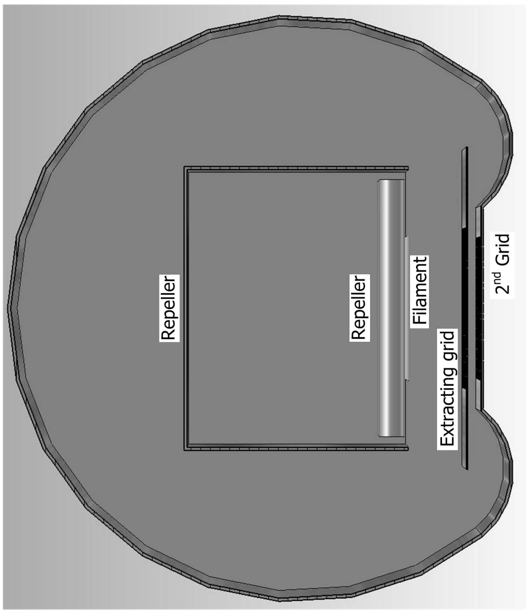

Fig.4 Cross view of filament and grid structure.

2.4 Ti foil window design

When electrons are accelerated by high electrical field between filament housing and exit window, they have to penetrate window membrane to radiate product within nitrogen atmosphere. Two main concerns made on design issues are window transparency of electron beam and heat dissipation on foil. Since the thinner titanium foil the less power deposition, a 10 μm titanium foil is taken advantage of and around 300 Watt heat is absorbed by this thin membrane. Besides, a copper rectangular plate having a series of perpendicular slots is used to support the foil in vacuum, which is fixed by pressure to the edges of the support plate covering slots and vacuum exit window. A good way to concentrate more electrons near central region to decrease beam loss on vacuum wall is to extrude upper and down boundary part of filament housing toward cooper window forming a convergence electrical field as shown in Fig.5.

3 Simulation

Through careful calibration of filament structure, a satisfactory beam dynamics is fulfilled by CST Studio Suite[5] package, as shown in Fig 6. There are eight 10 cm long cathodes interior of filament housing in parallel with 7.5 cm spacing. The exterior diameter of filament housing is 18 cm and inner diameter of vacuum chamber is 50 cm. The two grids have the same potential which is about positive 100 V with reference to cathodes, while the repeller is –2 V compare to them. In practice, a motor in control panel box is used to tune the grid voltage from a distance. About 60% of accelerated electron beam from filament housing could successfully penetrate the titanium foil. The total electron beam current is about 21 mA when the filament structure has –200 kV relative to earth. And then the maximum electrical field in vacuum is about 7.5 MV/m near the round corner of second grid, which is less than critical electrical field (9 MV/m) in vacuum.

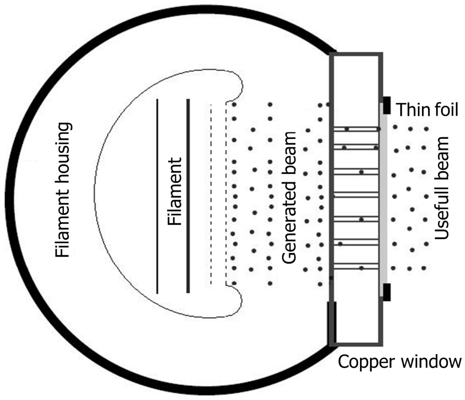

Fig.5 Cutaway view of the beam exit window.

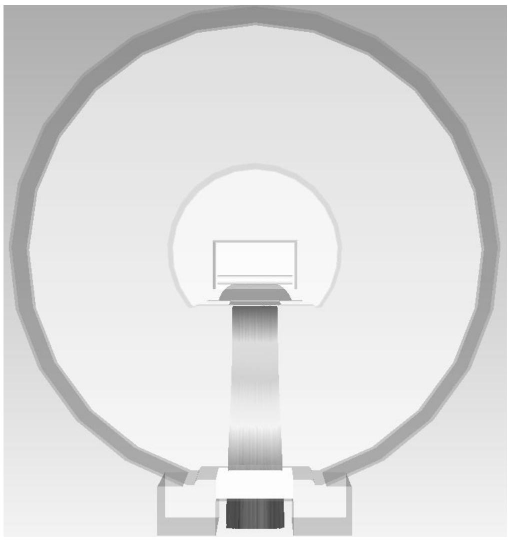

Fig.6 Electron beam trajectory simulation.

4 Present status

The prototype electron curtain accelerator system has finished installation and been in the process of high voltage exercise. Ceramic and glass plate high voltage breakdown was solved through craft modification by manufacturer.

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